Assessment of Mitten Crab (*Eriocheir spp.*) Monitoring Methods and Habitat Preference in the San Francisco Estuary.

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Development of a monitoring program for age-1+ Chinese mitten crab (*Eriocheir sinensis*) was continued in summer 2003. This was the third year of a 3 year study that was one component of an IEP Work Plan prepared by USFWS and DFG (Webb and Hieb 2001). The intent of the monitoring program was to identify upstream rearing areas as well as fast and inexpensive methods to detect age-1+ mitten crabs. Due to the previously reported variation of sampling methods and habitat types inhabited by mitten crabs, we tested two general hypotheses in 2003:

1) There is no relationship between measurable habitat parameters and age-1+ mitten crab abundance.
2) There is no difference in the efficacy of different detection methods for age-1+ mitten crabs.

We conducted surveys employing several different methods throughout summer 2003 to assess the relative effectiveness of various detection methods and to relate physical habitat parameters to the relative abundance of age-1+ mitten crabs. At each site quantitative habitat characteristics were measured including; salinity, electrical conductivity, temperature, stream velocity, stream depth, and intertidal bank height. Difficult to measure variables such as vegetation characteristics, substrate type and soil texture were estimated so that descriptive statistics could later be used to suggest likely relationships between variables that might warrant further investigation.

INTRODUCTION

The presence of the Chinese mitten crab in the San Francisco Bay and Sacramento-San Joaquin River Delta (San Francisco Estuary) was first confirmed in 1994 from crabs collected by shrimp trawlers in South San Francisco Bay (Cohen and Carlton 1995). Since that time the mitten crab has become a ubiquitous species in the estuary and its watershed. Monitoring data indicate that the Chinese mitten crab population has declined since 1999 (Rudnick et al. 2003), but this decline is unlikely to be permanent.

Evidence from European introductions indicates that annual mitten crab populations can be highly variable annually and cyclic over decades (Gollasch 1999, Clark et al. 1998). European populations have rebounded after each decline indicating that multi-year decreases are not necessarily linked to a permanent population decline (Rudnick et al. 2003). Individual female mitten crabs produce between 250,000 and 1,000,000 eggs in a brood (Cohen and Carlton 1995) making it unlikely that mitten crabs will be extirpated from any large estuary by natural processes.

Ecology of Chinese Mitten Crabs in the San Francisco Estuary

The Chinese mitten crab is a catadromous species that rears in fresh water and spawns in saltwater (Veldhuizen and Stanish 1999). Eggs hatch from late winter to early summer (Cohen and Carlton 1995) and mitten crabs mature through 5 larval stages, culminating in a megalopae stage (Veldhuizen and Stanish 1999). The megalopae settle to the substrate in brackish water and the young crabs migrate upstream to rear, primarily in brackish sloughs and freshwater areas immediately upstream of brackish water (Hieb, personal communication 2003). In their second year, many crabs migrate further upstream to freshwater rearing areas that may be over 100 km from where they hatched (Hieb, personal communication 2003). It is not yet known why mitten crab megalopae select particular streams or rivers to rear in. In the late fall adult crabs from 2 to 5 years of age migrate downstream to salt water where they reproduce and die (Rudnick et al. 2003). While much is known, the lifecycle of the Chinese mitten crab in the San Francisco Estuary is not yet fully understood.

Mitten Crab Ecology in the San Francisco Estuary

USFWS employees began investigating the mitten crab after it was first confirmed in the San Francisco Bay in 1994. Rudnick et al. (2003) summarizes research conducted on the abundance, ecology and population characteristics of mitten crab in the San Francisco Estuary. Since 1994 researchers have employed a variety of mitten crab sampling methods including baited traps, passive traps and direct observation. However, the relative ability of different sampling methods is unknown and few methods have met the desirable criteria of being fast and inexpensive.

Currently there is insufficient long-term data to accurately predict mitten crab year-class size before the downstream reproductive migration begins (Rudnick et al. 2003). In addition, since the efficacies of sampling methods are unknown it is difficult to accurately estimate the relative abundance of mitten crabs in any particular area. From the data available it appears that mitten crab population has varied greatly in the estuary from relatively low levels to very high levels, with a peak in 1998 (Hieb, personal communication 2003). This pattern of highly variable population size is similar to patterns seen in European mitten crab populations (Gollasch 1999, Clark et al. 1998).

ABBREVIATED METHODS

In 2003, development of a mitten crab monitoring survey consisted of sampling studies at randomly selected sites and a sampling methods comparison at sites with known mitten crab population. Any observations made by researchers in the course of sampling, even if the observation was not a direct result of the method used, were recorded as an observation associated with that sampling method. For example when a researcher, who was fishing, noticed a mitten crab walk by the size of the crab was estimated and recorded as observed during fishing.

Sampling at Randomly Selected Sites

In order to assess the habitat preferences of mitten crab different sampling methods were used at randomly selected sites, from general areas where mitten crabs had been reported in previous years (USFWS 2003). Both passive and active sampling was conducted at sites primarily within the Sacramento - San Joaquin River Delta (Delta).

Passive habitat sampling was conducted in three general areas between June 10 and August 14, 2003. Passive habitat traps were from the design of the artificial shelter traps used by Veldhuizen (2003) and consisted of 12 pieces of 16 cm long, 5 cm wide poly vinyl chloride (PVC) pipe lashed together in a PVC pipe and plastic mesh cube, with one open side. Traps were placed in tributaries of the Sacramento River (Dry Creek, the Feather River and Horseshoe Bend), the San Joaquin River (Shiloh fishing access and Caswell Park) and San Pablo Bay (Tolay Creek and northern Napa-Sonoma Marsh). Traps were placed in streams for at least 1 week prior to being checked, to allow resident mitten crabs to become acclimated to the trap presence. These traps were checked every week. In addition to the three primary sampling regions, one trap (already present) was checked twice in Coyote Creek, a South Bay tributary.

The first phase of active sampling (June 3 - July 10, 2003) consisted of walking transects and conducting a visual survey for mitten crabs. A transect was defined as a 20 meter long line on one side of a stream. At each site the sampler would walk the 20 meter transect slowly with a net in hand observing and looking from side to side for any crabs within the transect.

The second phase of active sampling (July 15 - August 14, 2003) consisted of baited fishing using a Kershaw's Crab Grabber and a snag trap. At each site fishing was conducted with 2 fishing poles, 1 pole for each type of trap, for a total of 30 minutes. Sardine (*Sardonella longiceps*) and chicken liver were alternately used as bait in the crab grabber and the snag trap.

Researchers recorded the sex and carapace width of all mitten crabs caught during sampling. The carapace width was estimated for any crabs that were observed, but not caught.

Comparison of Methods at Sites with Known Mitten Crab Populations

A supplemental study was conducted, from August 18 to August 30, 2003, to examine the efficacy of several sampling methods. The best sampling methods, as determined by literature reviews, USFWS experiences and consultation with other biologists were selected for trials at sites with known age-0+ mitten crab populations. Sampling was conducted in DFG's Ringstrom Unit in northern Napa-Sonoma marsh and Coyote Creek in South Bay, since no crabs were found in or upstream of the Delta during summer sampling.

When samplers arrived at the site the passive habitat traps were checked for crabs. After checking traps the samplers began active fishing, using 2 fishing poles rigged with baited crab grabbers. One crab grabber was baited with a threadfin shad (*Dorosoma petenens*) and the other crab grabber was baited with chicken liver and each was fished for a 30 minute period. When the fishing ended, baited stakes were placed to attract crabs. At each site 3 stakes were used. Each stake was baited with chicken liver, threadfin shad or sardine. Stakes were hammered into shallow stream banks so that the baits were submerged by 5 to 10 cm of water, but were still visible. Once the stakes were placed the sampler would step back far enough to assure that their shadow was not covering the baits or nearby water, and timing began. The sampler then recorded any mitten crabs that approached or fed on baited stakes for 30 minutes. The carapace widths (CW) of the all crabs were visually estimated in mm.

Analysis of Results

All statistical analyses were conducted using SPSS 11.5 statistical analysis software. Data from randomly selected sites were analyzed using step-wise linear regression, as described in McClave and Sincich (2000), to fit the best model to the data. Linear regression was used to model the effect of habitat parameters on passive habitat trapping observation per sampling effort (OPSE), visual transect OPSE and baited fishing OPSE.

Analysis of Variance (ANOVA) was used to analyze data, from method comparison trials, at the two sites known to be populated with mitten crab. A one-way ANOVA was used to compare group mean OPSE between trapping methods and group mean crab size between different trapping methods.

RESULTS

Results at Randomly Selected Sites

Of 55 passive trapping samples conducted during this phase, a total of 24 mitten crabs were observed. Passively trapped crabs ranged from 7 to 48 mm in CW, 71% were male, 21% were female and 2% were unknown.
Of 58 transects sampled only 2 yielded traces of mitten crab. In 1 transect pieces of a dead mitten crab were found and in 1 transect a mitten crab molt was found. Of 45 baited fishing samples, using a crab grabber on one pole and a snag trap on the other pole, only 1 crab was observed feeding on bait. No significant relationship could be detected between the crabs observed feeding and any measured habitat variables.

Table 1 displays summary statistics on the efficacy of different sampling methods employed at randomly selected sites between June 3 and August 14, 2003. No statistically significant relationships were found between habitat parameters and mitten crab abundance (α =0.10). The relationship between salinity and passive trapping observation per unit effort (OPSE) was highly significant ($p = 0.002$), but salinity alone explained little of the variation in OPSE around the mean (R^2 =0.18) and was clearly influenced by the large number of relatively low salinity samples with no crabs.

Results of Method Comparison at Sites with Known Mitten Crab Populations

When sampling methods were compared, passive habitat traps yielded the highest mean OPSE followed by fishing with 2 crab grabbers and baited stake observation. Passive trapping averaged 0.8 OPSE, fishing with 2 crab grabbers averaged 0.5 OPSE and the stake and watch method averaged 0.4 OPSE. An ANOVA performed on these differences, however did not reveal statistically significant differences in the group mean OPSE between observation methods (α = 0.10).

The mean size of crabs caught by the different methods varied such that passive trapping tended to catch smaller crabs (mean CW = 18 mm) when compared to the other two methods, displayed in Table 2. The mean size of crabs observed by fishing and the stake and watch method was identical (mean CW =35mm). An ANOVA performed on these results, however did not reveal statistically significant differences in the group mean crab size between observation methods (α = 0.10).

An interesting discrepancy was noticed when comparing apparent bait preference between methods. Crabs observed using the baited stakes method appeared to favor shad and sardines over chicken liver (Figure 1). A one-way ANOVA test confirmed that the OPSE for shad and sardine was significantly higher than the OPSE for chicken liver ($p = 0.000$, $p = 0.005$ respectively). In contrast, fishing with crab grabbers resulted in an identical number of crab observations when chicken liver or shad was used as bait.

DISCUSSION

General monitoring methods including mitten crab counts at fish salvage facilities and citizen reports to the mitten crab reporting system indicate that the 2003 adult mitten crab population in the San Francisco Estuary is substantially lower than the historic peak in 1998 and the lowest since 1996, when crabs were first collected in the Delta (Hieb, personal communication 2003, USFWS 2003). It is equally evident that mitten crabs have not been extirpated from the San Francisco Estuary.

The cause of the large annual variability in the San Francisco Estuary's mitten crab population size is unknown, but authors have speculated about causes of similar population variation in Europe. For example, in the Thames River estuary of England a large increase in the relative population of mitten crabs was observed since 1992; prior to 1992 the population had been relatively constant since the 1970s (Clark et al. 1998). The increase is believed by some to be due to improved mitten crab settlement coinciding with several years of local drought (Atrill and Thomas 1996). The San Francisco Estuary's mitten crab population will likely be highly variable from year to year as seen in other regions where they have been introduced (Rudnick et al. 2003).

The current study confirms the wide range of habitats in which mitten crabs are found (Table 3). This finding agrees with the observations of other researchers (Rudnick et al. 2003, Veldhuizen 2003). Given the small number of crabs collected and observed over the summer of 2003 and the variability of habitats in which mitten crabs were found, it is not surprising that no meaningful or significant relationships could be found between quantifiable habitat parameters and relative mitten crab abundance.

A statistically significant positive relationship was found between salinity and passive trapping OPSE, but little of the variation around the central OPSE trend could be explained by variation in salinity. This finding appears to be driven by the large number of samples in freshwater streams with no crabs and few samples in brackish water with crabs. There are several possible interpretations of this finding, but the small sample size limits the ability to make any definitive inference. The low variability explained probably indicated that both salinity and passive trapping OPSE are related to some other variable such as; proximity to the San Francisco Bay, food resources, or other unmeasured habitat parameters. Passive traps also selectively catch smaller mitten crabs, which are more likely to be present in brackish water (Hieb, personal communication 2003).

When sampling methods were directly compared, passive habitat trapping had the greatest success, followed by fishing with crab grabbers and the baited stakes method. While not statistically significant, there did appear to be a clear trend in the efficiency of different observation methods. It is also worth noting that the baited stakes and fishing methods take approximately 45 minutes per sample, compared to approximately 10 minutes per sample to check passive traps. The baited stakes procedure also limits crab data collected since crabs are not actually caught. Other studies have also indicated that passive habitat trapping is the most likely method to observe mitten crabs, when compared to other available methods (Veldhuizen 2003). One caveat of using passive habitat traps is that sampling results are biased toward catching smaller mitten crabs. On the other hand the detection of smaller crabs would result in 1-2 years for decision-makers to adjust programs to manage the downstream migration of the sampled year class as adults.

The baited stake sampling suggested that shad was the preferred bait followed by sardine while chicken liver was not sought by mitten crabs. These findings contrast with data from crab grabber fishing which suggests that mitten crabs feed on chicken liver and shad equally. There are at least two possible explanations for the contradiction in these data. The most likely explanation is that the sample size was so small that any detected differences are simply an artifact of stochastic feeding differences. Another possibility is that crabs in deep water are less particular about feeding. The fact that average fishing water depth was 60 cm compared to 19 cm for baited stakes might have influenced the bait selection. Perhaps the greater risk of approaching bait in relatively shallow water is only attractive if the reward is shad or sardine.

SUGGESTIONS FOR FUTURE RESEARCH

Results of this three year study are inadequate to suggest the best methods to detect age-1+ mitten crabs. Future sample method comparison and bait preference studies for age-1+ mitten crabs should be carried out in a controlled environment to elucidate differences in efficacy. Future monitoring efforts, in any area as large as the San Francisco Estuary, could use passive habitat traps to efficiently gauge relative abundance of, less then 48 mm carapace width, age-0+ crabs. If systematic monitoring is carried out regularly, at many locations throughout the Delta, over a period of years it should be possible to predict year class strength 1-2 years in advance of downstream migration of adults and potentially to correlate population size with water temperature, freshwater outflow and other variables that may control year class strength.

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NOTES

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